LLNL-TR-824904

Marshall Islands Dose Assessment and Radioecology Program

2018 Visual Study Report on the Cactus Crater Containment Structure: Supplement to Webpage Reporting

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June 2021

Disclaimer

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344, Lawrence Livermore National Security, LLC.

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Section 1

Background

This document provides a written supplement to web-based reporting on the 2018 visual study of the Cactus Crater Containment Structure on Runit Island. The visual survey was conducted during October 2018 using an Unmanned Aircraft System (UAS) carrying a DSLR camera to capture high resolution images and video of the structure.

The Operational Plan for the survey was developed and implemented by the U.S. Department of Energy (DOE) under the Marshall Islands Program. The survey was funded by the DOE as an interim measure to allow for project continuation and fulfill periodic reporting requirements established under clause (B)(i)(I) of the Public Law P.L. 112–149, Insular Areas Act of 2011, to perform a visual study of the concrete exterior of the Cactus Crater Containment Structure on Runit Island.

Public Law (PL) 112-149, Insular Areas Act of 2011, was amended under the Compact of Free Association Amendments Act of 2003 by assigning responsibilities for monitoring the Cactus Crater Containment Structure on Runit Island (also known as Runit Dome) to the Secretary of Energy (U.S. Department of Energy, U./S. DOE). This order required the Secretary to "periodically (but not less frequently than every 4 years) conduct -- (i) a visual study of the concrete exterior of the Cactus Crater Containment Structure on Runit Island; and (ii) a radiochemical analysis of the groundwater surrounding and in the Cactus Crater Containment Structure on Runit Island." 48 U.S.C. 1921b(f)(1)(B)(i). The Secretary was also directed to submit a report to Congress describing the results of visual surveys and radiochemical analyses of groundwater and "a determination on whether the surveys and analyses indicate any significant change in the health risks to the people of Enewetak from the contaminants within the Cactus Crater Containment Structure" 48 U.S.C. 1921b(f)(1)(B)(ii)(II).

Details concerning a visual survey conducted during 2013 are given elsewhere [LLNL TR 648143]. The 2013 survey report contains an extensive discussion on the history of site, on key design features of the containment structure and provides a listing of recommendations on implementation of the project. In general, findings from this previous survey report show that many concrete panels or segments contain minor visual defects consisting mostly of chipped "spalled" panel corners, surface cracks running across the panel segments and/or rooting vines and grass growing along panel seams or in panel corners. Most of the surface cracks were less than 1 to 2 millimeters in width. Many of the cracks contained chipped "spalled' edges with the degree of spalling varying between the panels. The cracks and spalling of concrete were not viewed as structural in nature because there was no evidence pointing towards significant loss of ability of the concrete to bind constituents together. The number of panels containing significant spall elements was highest amongst panels in the lower ring rows (A through C). The intermediate ring rows (D through F) contained both the highest density and the most significantly cracked panels. It was reported that cracks in the concrete were likely caused by long-term drying shrinkage of the concrete, and that chipping of edges and spalling by thermal movement of the slab due to expansion and contraction. Some panels also showed variations in roughness and level of discoloration. It was concluded that the concrete cap covering Runit Dome is structurally sound and continues to provide an effective and erosion resistant crypt to seal off the radioactive material below. Some of the more severely cracked and spalled panels were recommended for repair to reduce rainwater infiltration down through the waste pile and to help alleviate public perception that overall effectiveness of the structure is comprised and allowing for harmful quantities of fallout contamination becoming available for human consumption.

At the time of the current survey, the DOE had yet to receive appropriation to allow for the full implementation of requirements in the Public Law. Nonetheless a work program was devised and implemented to carry out a series of pre-emptive steps with the goals of developing a scientifically defensible and credible scientific program in support of the Public Law.

In partnership with scientists from Lawrence Livermore National Laboratory (LLNL) and consulting engineers, the objectives of the continuing work program (2013–2021) have focused on the following:

1. Developing a work program that more clearly meets the full intent of the Public Law.
2. Ensuring all field operational activities can be carried out in a safe and environmentally protective manner.
3. Assessing the compression strength of the concrete cap and overall integrity of the structure to support drilling and borehole installation operations on the containment structure.
4. Developing an improved understanding of the nature, solubilization potential and isotopic content of fallout contamination contained in the waste pile.
5. Providing improved understanding of the impacts of forcing events such as diurnal tides, wind speed and direction, rainfall and storms on water quality, and the potential for export of fallout contamination away from the site boundary in groundwater flows.
6. Developing a scientific basis for establishing the frequency of sampling under a long-term groundwater monitoring program that allows for meaningful interpretation of changes in water quality.
7. Providing cosmetic repair of surface concrete and eradication of rooting vines (this work has been funded independently by the DOE).
8. Providing essential data and information to develop a predictive model of the long-term health and ecological impacts of any leakage of radioactive contaminants from the containment structure.
9. Providing open, transparent, and accessible reporting on the status of the project to include informal interactions with stakeholders.

With an increment of new funding received from the Department of Interior (DOI) in 2019, the current workplan is to develop a series of groundwater sampling boreholes surrounding and in the Cactus Crater Containment Structure on Runit Island for groundwater samples to be collected from different depths down through the waste pile and into the natural geologic materials below (Hamilton, 2020c).

Note: Also see a related animation on the proposed drilling operation (Hamilton and Chen, 2019).

A key consideration is to allow for groundwater samples to be collected in such a manner that they provide a good representation of groundwater (and water quality) through the entire saturated zone below the structure. To date, the only assessable groundwater sampling point on the containment structure is a very shallow borehole left in place by the National of Sciences (NAS) in 1980.

Note: Options for disposal of drill spoils and any associated waste are still under investigation.

Several suitable qualified drill operators have been invited to bid on the project. Upon completion of the drilling phase of the project, a groundwater sampling and analysis program will be conducted in such a manner to allow for changes in groundwater quality to be assessed in association with forcing events such as the impact of tidal fluctuations, heavy rain fall and/or small or large-scale storms. This will require high resolution (at least monthly) sampling of the groundwater over several seasonal cycles to better define what changes may occur in water quality under different forcing conditions. It is only then that a meaningful decision can be made about the required frequency of groundwater sampling. Collection of data and information during this initial period of higher resolution sampling will also be required to:

(i) Develop a predictive model of the long-term health and ecological consequences of fallout contamination leaving the site boundary and being taken up by marine organisms used for human consumption.

(ii) Assess possible changes that may occur in water quality surrounding and in the Cactus Crater Containment Structure due to sea level rise.

Section 2

Methodology

Unmanned Aerial System (UAS) Survey

The need to develop an aerial platform for conducting visual surveys was driven by concerns about acquiring consistent visuals and providing adequate documentation of the condition of concrete panels. The 2013 survey was conducted over several days using a handheld camera at oblique angles to the surface of the concrete (Hamilton, 2013). The photographic record of concrete panels was variously affected by the dampness and puddling of the concrete, angle of the sun and other shadowing effects caused by cloud coverage. By using a UAS, the entire structure was surveyed in hours rather than days with the camera facing directly down. -

Utilizing experience gained by the LLNL Independent Diagnostic Scoring System (LIDSS) test flight group, a new survey UAS was built on a VulcanUAS airframe like that shown in **Fig 1**. The UAS is a coaxial octorotor setup using a PixHawl2.1 flight controller. The propulsion system consists of a KDA 55 HVC speed controllers, 4215XF-465 motors and 15-inch propellers. The unit carries a Gremsy T3 3-axis stabilizing gimbal and Canon 5D Mark III DSLR camera. A seagull #MAP2 is used to translate autopilot servo outputs to camera shutter signals. The UAS operates on a MaxAmps 2200mAh 6S LiPo battery and weighs about 23lbs.

Flights were performed using a target resolution or ground sampling resolution (GSD) of <0.5 cm/pixel using 80% front overlap and 70% side overlap. The main photo survey (Plan 2) was conducted with a GSD of 0.39 at an altitude of 15 m and flight speed of 3 m s^{-1} with the camera pointing straight down **(Fig 2)**. This survey was broken into two flights occupying about 17 minutes and produced about 550 photos. Supplemental flights were made at an altitude of 22 m (Plan 1, producing about 370 photos over 12 minutes), on a cross grid survey offset of 90° (Plan 3, camera in forward position by 7-10 degrees), and as an orbit with the Point of interest (POI) set at the apex of dome with the camera set in video mode (Plan 4). Images were compiled into an 3D model animation and Orthomosaic using Pix4DMapper drone software.

Fig. 1. Primary Survey Unmanned Aircraft System (UAS).

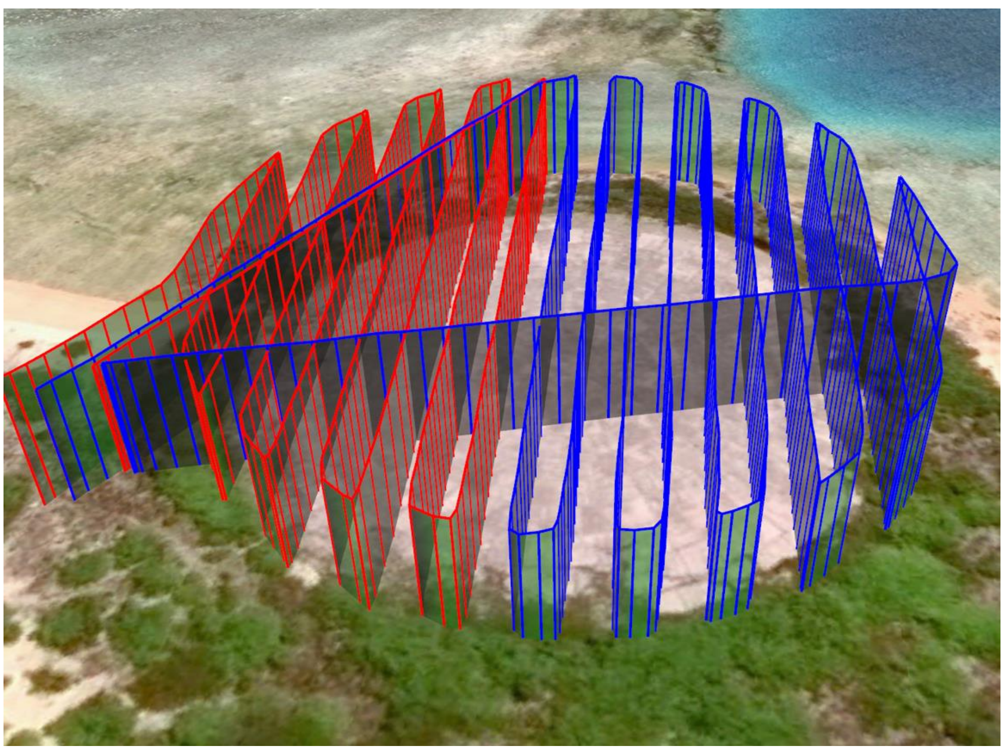


Fig. 2. Flight Plan 2 - 15 m elevation.

Concrete Repair

Maintenance activities to repair cracked and spalled concrete panels were performed to address widespread social media and public perception that cracks in the surface concrete allow for potentially harmful quantities of fallout radioactivity becoming available for human exposure (after Hamilton, 2013). Concrete repair was also used to establish a modern-day baseline to *help elucidate smaller scale changes occurring in the condition of the concrete over time.*

All concrete repairs were conducted under the supervision of a licensed engineer (CEL, Inc. Oakland, CA) using a Standard Operating Procedure (SOP) (Hamilton, 2019a and earlier editions). The work was funded under the regular DOE Marshall Island Program in what was viewed as an essential requirement in addressing stakeholder concerns in relation to on-going studies conducted under Public Law 112-149.

The surface concrete of the Cactus Crater Containment Structure was repaired using a combination of pre-packaged cement-based mortar (Structural Concrete® V/O) supplied by Five Star Products, *Inc*., and CRACKBOND® products from Adhesive Technology Corp., Pompano Beach, Florida (Hamilton, 2019a).

Five Star Structural Concrete® V/O is a high strength, rapid setting, one component, permanent concrete repair material used primarily for vertical and overhead structural repairs. The material produces a repair which is dimensionally stable, develops an integral bond to existing concrete, and restores structural integrity within hours of placement (*Five Star DESIGN-A-SPEC™ Guidelines*). The CRACKBOND® family of products are two component, high strength structural epoxy formulations specifically designed to repair cracks in concrete.

Machine cutouts of the cracks were made along the entire length of the crack extending out to about 4-6 inches using a CC-100 Walk-Behind Crack Chaser (manufacturer – U.S. Saws) coupled to an Ultra-Vac 1250 powered by a Honda Gas Engine to control resuspension of cement dust.

General maintenance activities of the containment structure are on-going. Local workers have been recruited and trained to periodically (every 3 to 6 months) access the site to remove rooting vegetation between the concrete segments and report on any significant changes on the overall integrity of the structure. It is also expected that remaining repairs to the surface concrete will be completed with oversight from a licensed engineer prior to the next scheduled visual UAS survey.

Section 3

Results

Unmanned Aircraft System (UAS) Visual Survey

Results of the 2018 visual study of the Cactus Crater Containment Structure are shown as a series of electronic deliverables accessible on the Marshall Islands website.

(i) **3D Model Output**. Viewable Low Resolution jpg image of the Cactus Crater Containment Structure on Runit Island.

An outline of the mosaic is shown in **Fig 3**. The 3-D textured output file can be downloaded from the link given below or from the website. The file can be saved and viewed and is readily shared via email.

The *web accessible images of selected individual panels have been included in this hard copy report with associated images of the same panels taken from the 2013 visual survey report* [LLNL-TR-648143]. *See Appendix I.*

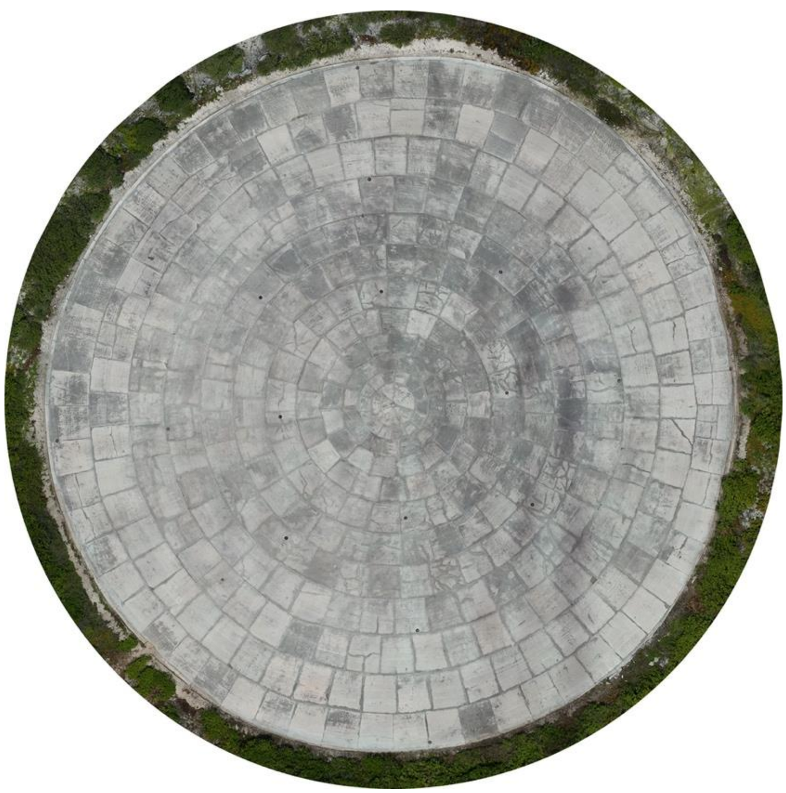


Fig 3. 3D Model Output from the UAS Survey of the Cactus Crater Containment Structure.

(ii) **Orthomosaic Output.** Photo Mosaic Record of the Cactus Crater Containment Structure on Runit Island

This file was generated for advanced users interested in viewing surface features of surface concrete. The high-resolution Orthomosaic TIFF file cannot be accessed directly from the website. Please send a request to [Terry Hamilton] for access to download the image.

It should be noted that viewing of this large file (app. 1.5 GB) can be cumbersome with use of most native image viewers.

Start by copying the image file over to your computer.

These non-commercial viewers are available to download for free on the internet to view the file:

1. IrfanView (iview451_x64_setup.exe).

Viewing and zooming in on the Orthmosaic. Freeware for non-commercial use supporting Windows XP, Vista, 7, 8, and 10. The software is available in 32 and 64- bit. Refer https://www.irfanview.com/ for download instructions and usage agreement.

2. QGIS (QGIS-OSGeo4W-3.20.0-4).

Recommended. QGIS is a professional GIS application licensed under the GNU General Public License. The current version is QGIS 3.20.0 'Odense' was released on 06/18/2021. Refer https://qgis.org/en/site/ for download instructions and access to the user guide, training manual, and QGIS tutorials. In the installer, choose **Express Install** and select **QGIS** to install the *latest release* or **QGIS LTR** to install the *long-term release*. The express installations have several optional packages including non-free software.

(iii) Runit Dome: Drone Flyover [LLNL-VIDEO-765358]

Video production from the 2018 visual study of the concrete exterior of the Cactus crater concrete containment structure on Runit Island. This video production shows a drone-flyover visual of the Cactus Crater Containment Structure to help document larger-scale deterioration in concrete panels and possible changes that may be occurring in the overall integrity of the structure and/or in the condition of the riprap placed along the oceanside shoreline as a protective sea wall.

(iv) Runit Dome: Keywall [LLNL-VIDEO-765360]

Video production from the 2018 visual study of the concrete exterior of the Cactus Crater Concrete Containment Structure on Runit Island. This video production provides a visual record of the condition of outside keywall extending around the N-E circumference of the dome and the riprap placed along the oceanside shoreline as a protective sea wall.

(v) 2018 Visual Study Report on the Cactus Crater Containment Structure: Supplement to Web Page Reporting, [LLNL-TR-824904].

Supplement to web-based reporting on the 2018 UAS visual survey of the concrete exterior of the Cactus Crater Containment Structure on Runit Island. Includes an outline of the various electronic reporting deliverables produced from the survey, a description of the methods employed, and example images of selected concrete panels shown in comparison with photos taken during the 2013 survey (from Hamilton, 2013).

Supplemental Brochures, Videos and Presentations

(vi) Technical Fact Sheet, The Runit Island Waste Containment Structure [LLNL-BR-755391]

Fact Sheet on the Cactus Crater Containment Structure (also known as Runit Dome. The fact sheet describes the status of knowledge pertaining to the possible impact of leakage of radioactive waste from the containment site into the environment. Draws on historical findings as well as more contemporary studies conducted in support of Public Law P.L. 112-149.

(vii) Runit Dome: 3D Animation [LLNL-VIDEO-765357]

Video production from the 2018 aerial survey of the concrete exterior of the Cactus Crater Containment Structure on Runit Island. Separate to mandated requirements and funding received under Public Law P.L. 112–149, the video production draws attention to efforts of the U.S. DOE to include cosmetic repair of concrete panels in the study as originally proposed by LLNL scientists (Hamilton, 2013a). A decision to include cosmetic repair of concrete under the project was considered essential in terms of addressing widespread media and public perception that cracks in the concrete allow for potentially harmful quantities of fallout radioactivity becoming available for human exposure. A secondary aim of *including concrete repair in the study was to establish a modern-day baseline to help elucidate smaller scale changes in the condition of the concrete over time.*

(viii) Public Law 112-149 Continued Monitoring of Runit Island. STRATEGIC ACTIONS, KEY FINDINGS AND FUTURE WORK [LLNL-PRES-771771]

Presentation briefing prepared for the U.S. Department of Interior (DOI) on the status of studies conducted under Public Law P.L. 112-149, Insular Areas Act of 2011.

Concrete Repair

A total of 46 cracked panels and 34 spalls identified in **Table 1** and **Table 2**, respectively, were repaired during the 2018 field mission to Runit Island. These initial efforts were focused on repairing cracks and spalls identified by Hamilton (2013) for priority repair. Two severely spalled elements (panel B1 and B43) with partially exposed underside to the waste pile constituents below were repaired on earlier field missions to Enewetak Atoll.

About 1,070 feet of crack was machine cut and filled with epoxy resin. There is about 1,128 feet of crack remaining across 35 different panels still in need of repair (Per comm, Jim Powers, CEL Inc). Example photos of the steps taken to repair the crack are given in **Fig. 4 a & b**.

Four (4) additional spalled sections of concrete were also identified for future repair. Plans to return to the site in 2019 to repair the remaining concrete panels were postponed due to outbreaks of measles and Dengue Fever in the Marshall Islands. The workplan has been further curtailed through 2020-21 due to the COVID pandemic.

Table 1. Crack Repairs Conducted on the Cactus Crater Containment Structure.

Panel ID	Date First Occupied	Crack Length (ft)	Panel ID	Date First Occupied	Crack Length (ft)
D35	9/23/18	19	No ID	9/29/18	19
E29	9/23/18	60	B57	9/30/18	19
C14	9/27/18	5	D01	9/30/18	35
D13	9/27/18	21	D15	9/30/18	38
D14	9/27/18	20	D36	9/30/18	28
D21	9/27/18	29	A22	10/1/18	19
D22	9/27/18	13	A23	10/1/18	30
D31	9/27/18	11	A24	10/1/18	30
E09	9/27/18	18	A25	10/1/18	19
E12	9/27/18	30	A26	10/1/18	19
E18	9/27/18	15	F27	10/1/18	65
B06	9/28/18	32	G29	10/1/18	38
D02	9/28/18	37	E22	10/2/18	67
D06	9/28/18	20	G23	10/2/18	14
D09	9/28/18	45	J12	10/2/18	14
B56 duplicate	9/29/18	40	K11	10/2/18	7
B57 duplicate	9/29/18	19	TopCap	10/3/18	89
C41	9/29/18	27	D29	10/3/18	17
C44	9/29/18	28	E24	10/3/18	71
D41	9/29/18	24	J10	10/3/18	23
Total Feet of Crack Repaired = 1070 feet					

Notes: Panel IDs taken from Hamilton (2013).

Table 2. Concrete Spall Repairs Conducted on the Cactus Crater Containment Structure.

Panel ID	Date First Occupied	Fill Type	Panel ID	Date First Occupied	Fill Type
A19	9/25/18	Concrete	C25	9/25/18	Concrete
A34	9/25/18	Concrete	C26	9/25/18	Concrete
A44	9/25/18	Concrete	D22	9/25/18	Concrete
A5 (A6)	9/25/18	Concrete	A2	9/26/18	Concrete
A54	9/25/18	Concrete	A4	9/26/18	Concrete
A55	9/25/18	Concrete	A50 (A51)	9/26/18	Concrete
A58	9/25/18	Concrete	A51 (A50)	9/26/18	Concrete
A6 (A5)	9/25/18	Concrete	A55	9/26/18	Concrete
B14	9/25/18	Concrete	A56	9/26/18	Concrete
B17	9/25/18	Concrete	A8	9/26/18	Concrete
B31	9/25/18	Concrete	A9	9/26/18	Concrete
B38	9/25/18	Concrete	A24	9/27/18	Epoxy
B40	9/25/18	Concrete	A28	9/27/18	Epoxy
B42	9/25/18	Concrete	A31	9/27/18	Concrete
B53	9/25/18	Concrete	A31	9/27/18	Concrete
C15	9/25/18	Concrete	A37	9/27/18	Concrete
C20	9/25/18	Concrete	A38	9/27/18	Concrete
C22	9/25/18	Concrete	A48	9/27/18	Epoxy
C22 Dup (as C24)	9/25/18	Concrete	A32	9/28/18	Concrete
Total Number of Panels Repaired = 34					

Notes: Panel IDs taken from Hamilton (2013).

Fig 4a. Repair Operations Topcap Section of the Cactus Crater Containment Structure
(showing the machine cut out of the cracks prior to filling with epoxy)
(October 2018)

Fig 4b. Repair Operations Topcap Section of the Cactus Crater Containment Structure
(showing the machine cutout of cracks filled with epoxy)
(October 2018).

Section 4

Summary

This document was prepared as a hardcopy supplement to website reporting of visual products developed from the 2018 UAS survey of the Cactus Crater Containment Structure on Runit Island. The products included downloadable and viewable low and high resolutions images of the containment structure (identified as a 3D-Model and Orthomosaic) along with associated video showing the more general nature of the structural integrity of the containment site.

A pre-survey inspection of the surface concrete failed to reveal any significant changes in the surface concrete compared with the photographic survey conducted in 2013. Over 1,000 linear feet of crack and 34 spalls identified in the 2013 survey were subsequently repaired and a UAS survey flown to capture high resolution images and video of the structure at the closeup of the mission. It is anticipated that all remaining repairs to the surface concrete will be completed prior to the next scheduled UAS visual survey.

It is expected that UAS surveys will help improve the ability of the program to produce more consistent visuals of the containment structure and, in association with current efforts to repair existing cracks and spalls, support efforts to investigate the rate of change of any future deterioration in the condition of concrete panels (and in the overall integrity of the site).

Section 5

References

This section contains a full chronological listing of reports, videos, presentations, other materials describing various activities undertaken by the U.S. DOE in partnership with LLNL scientists in support of studies associated with the Continued Monitoring of Runit Island, *Insular Areas Act of 2011* (*Public Law P.L. 112-149*). Many of these reports are accessible on the Marshall Islands website .

Davisson M. Lee, T.F. Hamilton, and A.F.B. Thompson (2012). Radioactive waste buried beneath Runit Dome on Enewetak Atoll, Marshall Islands, *Int. J. Environment and Pollution*, Vol. 49 (3/4), 2012.
Background information on the design and decision-making process leading up to the construction of the Cactus Crater containment structure at Runit Island on Enewetak Atoll. Discussion on the risks and uncertainties associated with the site. Justification on the need to conduct additional studies to develop a better understanding of the nature and integrity of the waste pile and on the solubilization potential of radioactive constituents encapsulated in the concrete.

Hamilton, T.F (2013a). A Visual Description of the Concrete Exterior of the Cactus Crater Containment Structure, Report, Lawrence Livermore National Laboratory, LLNL-TR-448143.
Visual survey mission report from 2013 in partial fulfilment of clause (B)(i)(I) of the Public Law P.L. 112–149 to perform a visual study of the concrete exterior of the Cactus crater concrete containment structure on Runit Island. In addition to a full photographic record of the concrete panels covering the structure, the report provides an extensive discussion on the history of the site and methods employed during construction. The report also identifies a series of recommendations for project continuation and future management of the site.

Hamilton T. F. (2013b). Update on the Enewetak Radiological Protection Monitoring Program, DOE-Enewetak Community Meeting, August 2013, Lawrence Livermore National Laboratory, LLNL-PRES-642042.
Community presentation (Kona and Enewetak Atoll communities) on the 2013 visual survey of the Cactus Crater Containment Structure on Runit Island along with a request for volunteer participation in the plutonium bioassay urinalysis program.

Hamilton, T.F (2014). A Visual Description of the Concrete Exterior of the Cactus Crater Containment Structure, Executive Summary, Lawrence Livermore National Laboratory, LLNL-TR-653147.
Executive summary of the 2013 visual survey report containing background information on the site, a list of key findings and conclusions drawn from the survey, and recommendations on project continuation.

Hamilton, T.F (2016). Talking Points: Enewetak-Ujelang Local (EULG) Government Briefing, Lawrence Livermore National Laboratory, LLNL-PRES-713239.

Briefing presentation on preliminary analysis of groundwater collected from on the Cactus Crater Containment Structure, effects made to secure funding from the Marshall Islands from the International Atomic Energy Agency (IAEA) to develop a national radioactivity monitoring capacity and suggestions on future work.

Hamilton T.F. (2018a). Technical Fact Sheet, The Runit Island Waste Containment Structure, Lawrence Livermore National Laboratory, LLNL-BR-755391/LLNL-WEB-755955.

Fact Sheet on the Cactus Crater Containment Structure (also known as Runit Dome). The fact sheet describes the status of knowledge pertaining to the possible impact of leakage of radioactive waste from the containment site into the environment. Draws on historical findings as well as contemporary studies conducted in support of Public Law P.L. 112-149.

Hamilton T.F. (2018b). The Runit Island Waste Containment Structure (*Runit Dome*), Lawrence Livermore National Laboratory, LLNL-POST-755953. English edition.

English language visitor poster board Runit Island.

Hamilton T.F. (2018c). Nien Kakwon Kwopij in Radiation Jen Kamelmel ko Enewetak, eo im et Naetan (*Runit Dome*), Lawrence Livermore National Laboratory, LLNL-POST-756763. Marshallese edition.

Marshallese language visitor poster board Runit Island.

Hamilton T.F., P. Nyholm, and J.S. Wynn (2018a), Runit Dome: Drone Flyover, Lawrence Livermore National Laboratory, LLNL-VIDEO-765358.

Video production from 2018 developed in partial fulfilment of clause (B)(i)(I) of the Public Law P.L. 112–149 to provide reporting of a visual study of the concrete exterior of the Cactus crater concrete containment structure on Runit Island. This video production shows a fly around visual of the Cactus Crater Containment Structure to help document larger-scale deterioration in concrete panels and possible changes that may be occurring in the overall integrity of the structure and/or in the condition of riprap placed along the oceanside shoreline as a protective sea wall.

Hamilton T.F., P. Nyholm, J.S. Stewart and A.C. Connell (2018b). Runit Dome: 3D Animation, Lawrence Livermore National Laboratory, LLNL-WEB-765357.

Video production from the 2018 aerial survey of the concrete exterior of the Cactus Crater Containment Structure on Runit Island. Separate to mandated requirements and funding received under Public Law P.L. 112–149, the video production draws attention to efforts of the U.S. DOE to include cosmetic repair of concrete panels in the study as originally proposed by LLNL scientists (Hamilton_LLNL-TR-648143). A decision to include cosmetic repair of concrete under the project was considered essential in terms of addressing widespread media and public perception that cracks in the concrete allow for potentially harmful quantities of fallout radioactivity becoming available for human exposure. An additional aim of *including concrete repair in the study was to establish a modern-day baseline to help elucidate smaller scale changes and visual defects in the condition of the concrete over time.*

Hamilton T.F. (2019a). Repair of Cracks and Spalls within the Concrete Façade Covering the Runit Island Waste Containment Structure_V2.0, Standard Operating Procedure (SOP), Lawrence Livermore National Laboratory, LLNL-TR-787458.

Informational document outlying materials and methods used to conduct cosmetic repair of the concrete cap covering the Cactus Crater Containment Structure.

Hamilton T.F. (2019b). Public Law 112-149 Continued Monitoring of Runit Island. STRATEGIC ACTIONS, KEY FINDINGS AND FUTURE WORK, Lawrence Livermore National Laboratory, LLNL-PRES-771771.

Presentation briefing to the U.S. Department of Interior (DOI) on the status of studies conducted under Public Law P.L. 112-149, Insular Areas Act of 2011.

Hamilton T.F. (2019c). Science Program Briefing: Public Law 112-149 Continued Monitoring of Runit Island, Lawrence Livermore National Laboratory, LLNL-PRES-774030.

Presentation at the U.S. DOE-GRMI Annual Meeting, Majuro Atoll, Republic of the Marshall Islands, May 15-16, 2019.

Hamilton T.F. and R.W. Chen (2019). Runit Dome: Groundwater Bole Hole Drilling Animation_V2.0, Lawrence Livermore National Laboratory, LLNL-WEB-777157.

Informational video production highlighting the positioning and structural elements of Runit Dome along with an animation of planned drilling operations to establish groundwater sampling boreholes. This work forms an essential and obvious prerequisite for meeting requirements under clause 9(B)(i)(II) of Public Law P.L. 112-149 to conduct radiochemical analysis of the groundwater surrounding and in the Cactus Crater Containment Structure on Runit Island.

Hamilton T.F., L.E. Bouthillier, and C. Hernandez (2019). Runit Dome: Keywall, Lawrence Livermore National Laboratory, LLNL-VIDEO-765360.

Video production from 2018 produced in partial fulfilment of clause (B)(i)(I) of the Public Law P.L. 112–149 to provide reporting of a visual study of the concrete exterior of the Cactus crater Concrete Containment Structure on Runit Island. This video production provides a visual record of the condition of outside keywall extending around the N-E circumference of the dome, and the condition of the riprap placed along the oceanside shoreline as a protective sea wall.

Hamilton T.F. (2020a). Non-destructive Testing and Evaluation Investigation of Runit Island Containment Structure, Runit Project Data Report, Lawrence Livermore National Laboratory, LLNL-TR-810290.

Full data disclosure of an independent report prepared by Olsen Engineering, Inc., with highlighted summary results and conclusions reported under LLNL authorship.

Hamilton T. F. (2020b). Exterior Concrete Core Test Results, Runit Project Data Report, Lawrence Livermore National Laboratory, LLNL-TR-810020.

Full data disclosure of an independent report released by Consolidated Engineering Laboratories (CEL), Inc., based on analysis of concrete core samples by Micro-Chem

Laboratories (Murphys, CA) *with highlighted summary findings reported under LLNL authorship.*

Hamilton T.F. (2020c). Drilling, Substrate Recovery and Sampling, and Installation of Groundwater Monitoring Wells on Runit Island, Enewetak Atoll, Republic of the Marshall Islands, Background Documentation, Revision 3, Lawrence Livermore National Laboratory, LLNL-TR-817635.

Draft Statement of Work (SOW)/RFP informational Document for distribution to prospective bidders on a subcontract award offered by the Lawrence Livermore National Security (LLNS) to drill a series of boreholes surrounding and on Runit Dome for development as groundwater sampling wells.

Hamilton T.F. (2021). Runit *Island Test Shot Animation,* Lawrence Livermore National Laboratory, LLNL-VIDEO-824726.

Potential impacts of any releases of radioactive contaminants from the Cactus Crater Containment Structure on Runit Island into the lagoon or ocean reef need to be compared with long-term solubilization of residual fallout deposition deposited directly in local marine sediment during the nuclear test era. There were 17 nuclear tests conducted in the immediate vicinity of Runit Island. The names, dates, and explosive yields of each of these test shots are shown in chronological order in this animation video (United States Nuclear Tests, July 1945 through September 1992, DOE/NV-209-REV 16).

A key finding from preliminary analyses of groundwater, local soil, lagoon waters and sediment shows that low yield tests conducted on and near Runit Island produced characteristic $^{240}Pu/^{239}Pu$ *isotopic ratios that appears to be very different to those observed from preliminary groundwater samples collected from in the dome. Also, except for heavy elements such as the plutonium isotopes, the concentration of other fallout radionuclides in offshore lagoon waters of Runit Island more closely resemble those observed in the open ocean. We conclude that the local marine radiation environment adjacent to Runit Island is dominated by plutonium mobilization from sedimentary sources to solution not from leakage of radioactive from the Cactus Crater Containment Structure.*

Hamilton T.F, and P. Nyholm (2021). 2018 Visual Study Report on the Cactus Crater Containment Structure: Supplement to Web Page Reporting, Lawrence Livermore National Laboratory, LLNL-TR-824904.

Supplement to web-based reporting on the 2018 UAS visual survey of the concrete exterior of the Cactus Crater Containment Structure on Runit Island. Includes an outline of the various electronic reporting deliverables produced from the survey, a description of the methods employed, and example images of selected concrete panels shown in comparison with photos taken during the 2013 survey (from Hamilton, 2013).

Appendix I

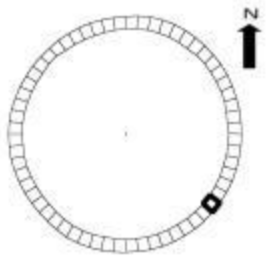
Comparative photos of concrete panels recorded during visual surveys of the Cactus Crater Containment Structure (2013-2018)

Panel A30

Description

2013. No significant or obvious interior cracks extending across the top of the panel. Minor spalling of concrete observed in the top and bottom left-hand corners, and in the bottom right-hand corner, of the panel.

2018. No significant changes in the condition of the concrete.



2013

2018

Panel B1

Description

2013. Significant spalling of concrete observed in upper right corner where the chipped-out piece of concrete extends down to contaminated soil – cement grout waste pile mixture below. Surface crack observed running across the full width of the panel at a mid-point up the segment. Rooting vegetation removed from along the panel seams. Panel recommended for priority repair.

2015. Repaired spalled patch of concrete. No significant changes in the condition of the concrete observed during 2018.

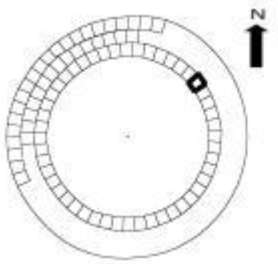
2013

2015

Panel C13

Description

2013. No significant or obvious interior cracks extending across the top of the panel. The panel has a rough and weathered appearance.
2018. No significant changes in the condition of the concrete.



2013

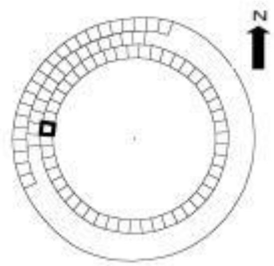
2018

Panel C 43

Description

2013. Significant spalling of concrete observed in the upper left corner of the panel where the chipped-out piece of concrete extends down to contaminated soil-cement grout waste pile mixture below. Some minor spalling/cracking of concrete also observed in the lower right-hand corner of the panel. Panel recommended for priority repair.

2015. Spalled patch of concrete repaired. No significant changes in the condition of the concrete observed during 2018.



2013

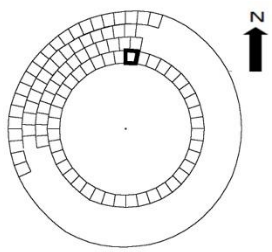
2018

Panel D5

Description

2013. No significant or obvious interior cracks extending across the top of the panel. The panel has a rough and weathered appearance. Some spalling/cracking of concrete observed in the lower right-hand corner of the panel. Rooting vegetation removed from along the panel seams. Panel contains a filled concrete borehole (CD-1) from the 1980 NAS investigation.

2018. No significant changes in the condition of the concrete.



2013

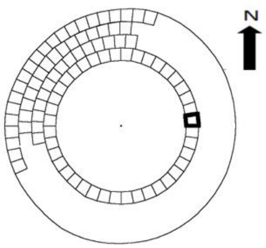
2018

Panel D14

Description

2013. The panel has a rough and weathered appearance. A surface crack observed extending up from bottom seam adjacent to the corner intersection C17/C18. Panel contains a vertical elevation benchmark.

2018. No significant changes in the condition of the concrete. 20 feet of pre-existing crack cut and filled with epoxy.



2013

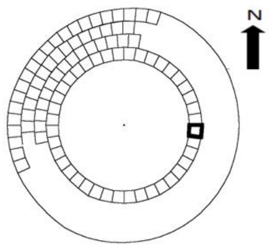
2018

Panel D15

Description

2013. This panel contains the most severe crack of any segment on the dome. The crack width exceeds several millimeters in some areas and runs left to right at about a mid-point up the panel as well as up and down the panel from an intersection point in the middle. The crack contained chipped 'spalled' edges. Panel recommended for priority repair.

2018. No significant changes in the condition of the concrete. 38 feet of pre-existing crack cut and filled with epoxy.



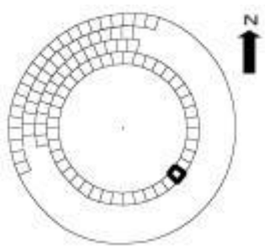
2013

2018

Panel D21

Description

2013. A crack observed extending upwards from a central position along the bottom seam adjacent to corner intersection C22/C23 and intersecting at corner E15/E16 on the ring row above. The crack branches out into a fork to the left edge at distances between 2 and 3 meters up from the base of the panel. The crack contains chipped ‘spalled” edges. Panel recommended for priority repair.
2018. No significant changes in the condition of the concrete. 29 feet of pre-existing crack cut and filled with epoxy.



2013

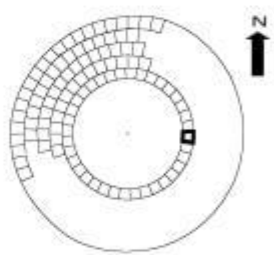
2018

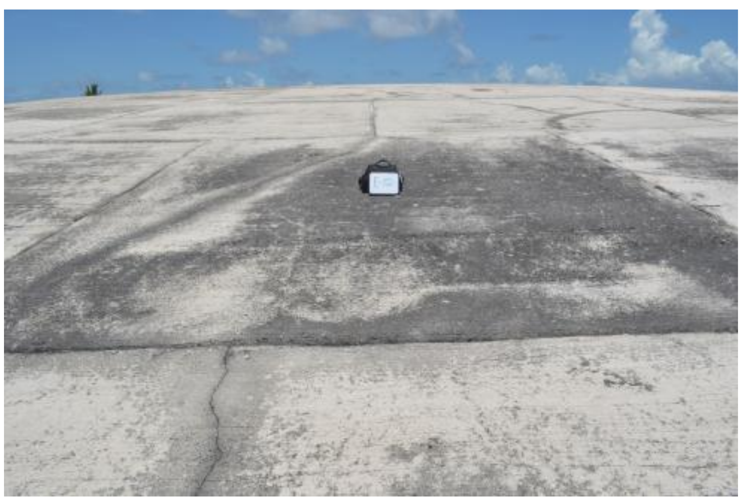
Panel E12

Description

2013. Panel has a rough and weathered appearance. Significant spalling/cracking of concrete observed in the upper left corner. The panel also contains a distinguishable crack extending up from the bottom left side of the panel and intersecting the upper seam at a position adjacent to the corner F9/F10 on the ring row above. Panel recommended for priority repair.

2018. No significant changes in the condition of the concrete. 30 feet of pre-existing crack cut and filled with epoxy.





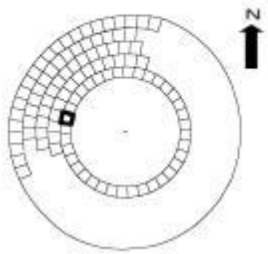
2013

2018

Panel E21

Description

2013. Some spalling/cracking of concrete observed in the upper left-hand corner of the panel. No obvious interior cracks or spalls extending across the top of the panel with exception of a small, voided piece of concrete in the upper right corner (app. 4 x 2-2.5 centimeters in area).
2018. No significant changes in the condition of the concrete.



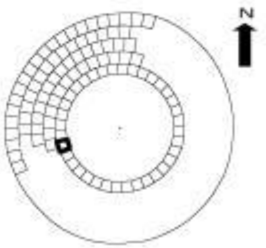
2013

2018

Panel E28

Description

2013. No significant or obvious interior cracks extending across the top of the panel. The panel has a rough and weathered appearance. Rooting vegetation removed from along the panel seams.
2018. No significant changes in the condition of the concrete.



2013

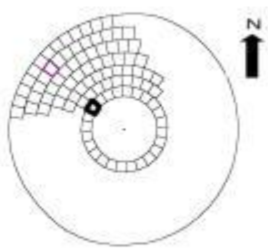
2018

Panel G29

Description

2013. Surface crack observed extending up through the middle of the panel from the left side of the bottom seam towards the upper right-hand corner with forks branching out to the left and right sides at about a mid-point up the panel. Rooting vegetation removed from along the panel seams.

2018. No significant changes in the condition of the concrete. 38 feet of pre-existing crack cut and filled with epoxy.



2018

Appendix II

Miscellaneous Photos

Before Cleanup

Cleanup of Cactus Crater Containment Structure (October 2018)

After Cleanup

Concrete Repair Operations Cactus Crater Containment Structure
(CEL Licensed Engineer, Mr. Jim Powers)
(October 2018)
(*Used with Permission*)

Concrete Repair Operations Cactus Crater Containment Structure
(October 2018)

Runit Aerial Survey UAS
(October 2018)

UAS Photo of the Cactus Crater Containment Structure (October 2018)

UAS Photo of the Cactus Crater Containment Structure
(*Lacrosse Crater in the Background*)
(October 2018)